Phase II Project Summary

Firm: CFD Research Corporation
Contract Number: NNX11CA27C
Project Title: Computational Tool for Coupled Simulation of Nonequilibrium Hypersonic Flows with Ablation

Identification and Significance of Innovation: The goal of this SBIR project is to develop a predictive computational tool for the aerothermal environment around ablation-cooled hypersonic atmospheric entry vehicles. This tool is based on coupling the relevant physics-based models to a hypersonic flow solver. We have coupled to the flow solver a general radiative transfer equation solver, a nonequilibrium radiative property modeling framework and a material response code to allow fully coupled simulations of hypersonic flows accounting accurately for 1) gas-phase chemical nonequilibrium 2) nonequilibirum radiation from dissociated species behind the shock 3) a detailed nonequilibrium surface chemistry, and 4) material response with coupled ablation and pyrolysis. Such a fully coupled analysis capability will significantly improve the state-of-the-art for modeling ablation and design of thermal protective systems in general.

Technical Objectives and Work Plan: The overall objective of this work is to develop a coupled tool for hypersonic flows with ablation. The specific technical objectives included development of 1) nonequilibrium surface chemistry models and their coupling to the flow solver, 2) nonequilibrium chemistry models for pyrolysis gases along with finite rate chemistry models, 3) a radiative transfer equation (RTE) solver module which could accurately account for participating media, surface-to-surface radiation in the presence of participating media, 4) a radiative property modeling framework to account for nonequilibrium processes present in a hypersonic shock layer and 5) a coupling framework to couple these models together into a single integral analysis software. The modular approach for coupling was demonstrated by coupling the RTE solver module with DPLR which is a NASA code of interest.

Technical Accomplishments: All technical objectives of Phase II have been accomplished by the SBIR team. The major achievements include: 1) successful implementation of a nonequilibrium surface chemistry module, 2) quantification of different nonequilibrium surface chemistry models on the aerothermal environment of the Stardust return capsule, 3) successful implementation of a multispecies pyrolysis gas formulation 4) development and validation of a volume-averaged finite-rate approach for carbon fiber oxidation in a material response code, 5) development of a general RTE solver framework including non-gray participating media, surface-to-surface radiation in presence of participating media and ability to model nonequilibrium radiation in the presence of hypersonic shock layers. A modular coupling framework was also developed and demonstrated, by coupling the RTE solver module with two different hypersonic flow codes LeMANS and DPLR. Detailed, fully coupled simulations of the Stardust re-entry were conducted with different levels of coupling between flow, material response and RTE solvers. Results show a significant potential and capability to do fully coupled simulations of re-entry type problems.

Potential NASA Application(s): Future NASA missions will be more demanding and will require better performing ablative TPS than currently available. The tool will find direct application in NASA technology development programs such as the In-Space Propulsion Technology Program, and also in NASA's Fundamental Aeronautics Hypersonics Project that aims to develop methods, tools and data that enable emergence of highly reliable and efficient hypersonic systems. The tool can be used to aid in the design and development of future planetary vehicles (such as the Orion Multi- Purpose Crew Vehicle, Mars Aerocapture and Mars Sample Return spacecraft) and components of future hypersonic vehicles.

Potential Non-NASA Application(s): Technology applications beyond NASA include the Theater and National Missile Defense vehicles performing exo-atmospheric missile intercepts, and missile warhead re-entry applications. The computational tool will also be relevant to the joint DOD/NASA effort called the National Aerospace Initiative (NAI) that involves, among other things, the development of air-breathing hypersonic vehicles. OEMs will also find the tool useful in exploring and designing newer and more robust ablative TPS materials and heat shield systems. The models developed in this SBIR project can also be ported to commercial CFD software such as ATAC, Fluent, CFD-ACE+ and CFD-FASTRAN.

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